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The Influence of Molybdenum Equivalent on the Anisotropy of Thermal Expansion of Titanium Martensite Lattice

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Abstract

The structure of the martensite formed by quenching in titanium alloys, as well as the connection between the rhombic lattice α - martensite and anisotropy of thermal expansion was investigated. The methods of the X-ray and thermal XRD phase analyzes have been used to study the relationship between martensite crystal lattice, the coefficient of thermal expansion (CTE) and molybdenum and aluminum equivalent.

Keywords: titanium alloys, martensite, CTE, XRD-analysi.

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1. Materials and Methods

The purpose of this study was to investigate the martensite structure, which is formed by a quench in titanium alloys, as well as the relationship between the rhombic of the α"- martensite lattice and the thermal expansion anisotropy. Model alloys Ti-8Mo, Ti-3Mo-6Al and industrial alloys VT6 (Ti-4V-6Al) и VT14 (Ti-3Mo-1V-6Al) alloy was used in this study. The analyzed chemical compositions and molybdenum equivalent of all four alloys are given in Table 1. The martensite was formed in titanium alloys by quenching from 1050 °C (from β-regions). After the preparation of metallographic thin sections through the method of electropolishing, follows the observation "in suty" during heating in BRUCKER Advance D8.

Optical microscopy (Nikon Epiphot 200) was performed to these specimens. Polished samples were analyzed by X-ray and thermal XRD which was carried out in a BRUCKER Advance D8 diffractometer operated with filtred Co K_α radiation (2θ=34...120°).

Table 1: The chemical composition of Titanium Alloys, mass. %.

Alloy	Al	Mo	V	Mo_{eq}
Ti-8Mo	0,22	7,35	-	7,6
VT14	4,84	3,12	1,05	4,0
Ti-3Mo-6Al	5,91	3,23	-	3,5
VT6	6,13	-	3,8	3,0

2. Results and Discussion

The microstructure of the quenched alloys consists of equiaxed grains β-phase with straight grain boundaries, which are the results of recrystallization in alloys (Fig.1). Martensite plates of different sizes were found inside the grain. The structure obtained is characteristic of titanium alloys of the martensitic class quenched from β-regions.

The results obtained by XRD analyzes Ti-8Mo are shown in Figure 2a. The diffracted peaks present are by orthorhombic martensite. In VT6 alloy with low molybdenum equivalent Mo_{eq}=3 α'-martensite was obtained and diffracted peaks are shown only when there is hexagonal lattice. An analysis of the diffraction pattern in alloys Ti-3Mo-6Al and Vt14 revealed a set of peaks, which are characteristic of the hcp lattice. Some of the diffracted peaks are broad and symmetrical, but the several peaks demonstrate a duality (fig. 2c,e). Diffracted peak relevant provision is of the 110 α (Ti-3Mo-6Al) in range 73...76 2θ, has a characteristic duality the peak. Accordingly, the definition of the martensite lattice was one of the additional tasks of the study. The definition of the lines and the calculation of the lattice parameters were performed using the "Topaz" program for the orthorhombic lattice. The characteristics of parameters of martensite lattice are shown in Table 2.

Table 2: Characteristics of martensite lattice.

Alloy	a, nm	b, nm	c, nm	R= $\sqrt{3}a/b$
Ti-8Mo	0,30238	0,49936	0,46669	1,049
VT14	0,29677	0,49985	0,46586	1,028
Ti-3Mo-6Al	0,29785	0,50025	0,46733	1,026
VT6	0,29362	-	0,46695	1

The observed shift of the peak when heating VT6 towards a smaller angle 2θ (Fig.2g), as a consequence of the increase of the grating periods on thermal expansion. The lines retain symmetry. On the thermal diffractograms of the Ti-8Mo alloy (Fig.2a) the behavior of the lines is noticeably different by a more intense shift from the initial position, with the line 200 changing its position by a degree when the temperature changes from 30 to 300 °C. The position of the 022 line remains nearly unchanged. On the contrary

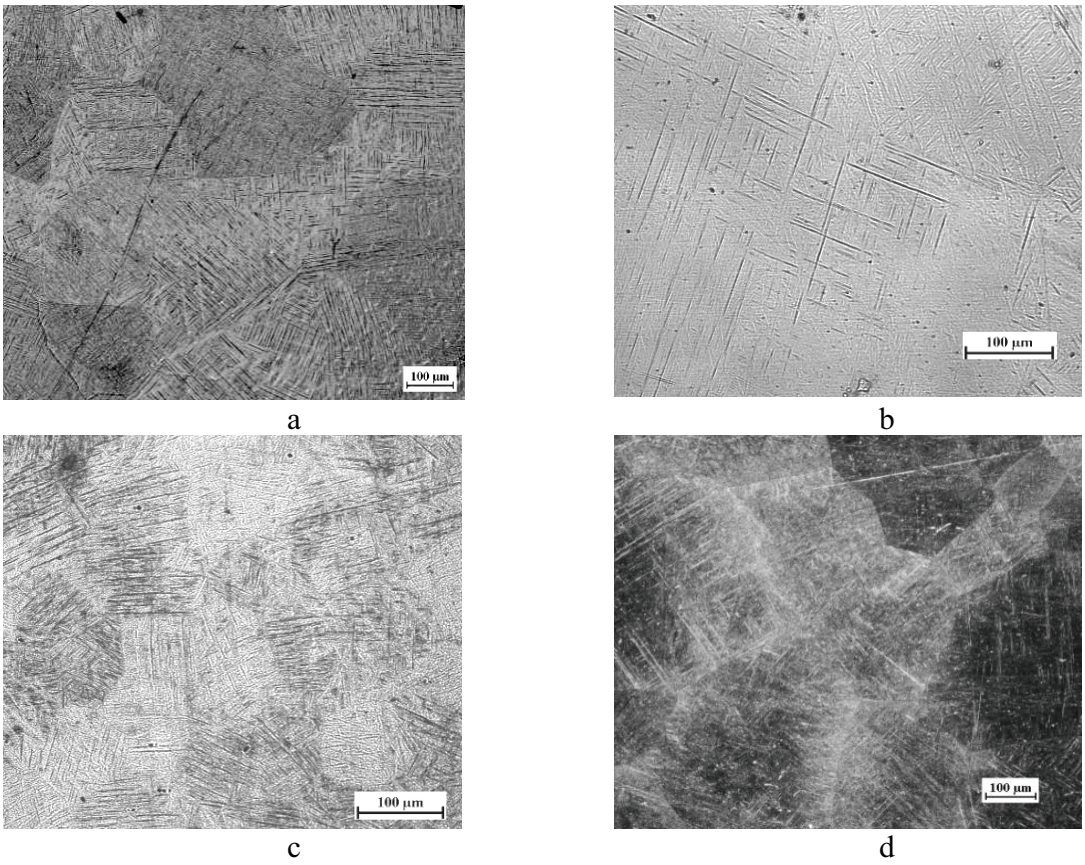

Figure 1: Microstructures after heat treatments (1050°C); a – Ti-8Mo, b –VT14, c – Ti-3Mo-6Al, d –VT6.

the position of the line 130 shifted towards large angles. The calculation of the lattice periods and their c hanges with increasing temperature showed that the period “b” of the orthorhombic lattice does not increase when

heated as it should be during thermal expansion in agreement with the literature but decreases. Nevertheless the thermal expansion of the alloy remains positive since the reduction of period “b” during heating is compensated by an intensive increase in period “a”. This effect is characteristic of the orthorhombic martensite lattice [1]. Accordingly, when the two remaining alloys were heated, the pattern of displacement of lines on the diffraction pattern and the behavior of the period “b” of the orthorhombic lattice were first monitored. The results of the calculations of the relative change in the lattice periods of these alloys are presented in the graphs (Fig.2b,d,f,h), which demonstrate the different nature of changes in periods ”a” and ”b” with increasing temperature. Note, that for a hexagonal lattice the changes “a” and “b” should be identical. In this situation, the period “b” practically does not change during heating. A review of the received results suggests that we can state unequivocally that when quenching these alloys, α”-martensite is formed, which disagrees with the well-established idea that α’-martensite can be obtained in alloy VT14 [2].

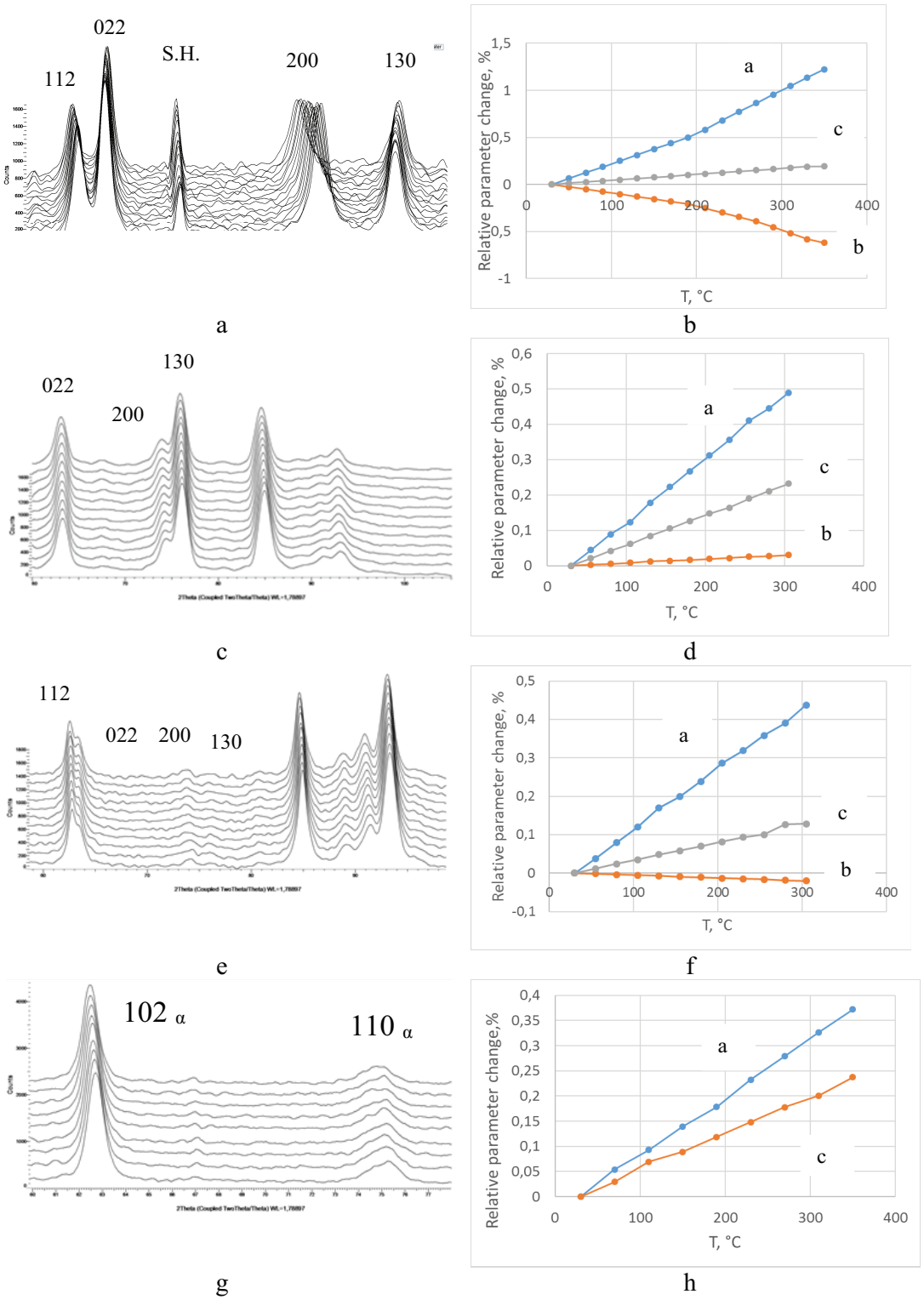

Figure 2: The diffractogram patterns of ”in suty” heating (a, c, e, g) and temperature depending of relative lattice parameters change (b, d, f, h) of alloys Ti-8Mo (a, b), Ti-3Mo-6Al (c, d), VT14 (e, f), VT6 (g, h), S.H. – sample holder.

Table 3 lists the corresponding values of the thermal expansion coefficient along crystallographic directions. In accordance with the data of the table, both hexagonal and

orthorhombic martensite based on the anisotropy of the CTE along the crystallographic axes of the lattice. If the anisatropy of the hexagonal lattice is relatively small, then in the orthorhombic lattice the anisotropy is more pronounced and its degree increases with increasing β-stabilization coefficient.

Table 3: The coefficients of thermal expansion α along crystallographic directions.

Alloy	α_a,10^6,K^{-1}	α_b,10^6,K^{-1}	α_c,10^6,K^{-1}
Ti-8Mo	39	-19	6
VT14	16	-1	4
Ti-3Mo-6Al	18	1	7
VT6	12	-	7

3. Conclusion

When assessing the effect of molybdenum equivalent on lattice changes during heating, it can be noted that, with an equal value of molybdenum equivalent, the aluminum equivalent plays a role in the anisatropy of thermal expansion.

It was established that thermal expansion of the martensite lattice, in the analysis of samples, has a clear anisotropy along certain crystallographic directions for all alloys. The coefficient of thermal expansion along the axis “a” exceeds the coefficients along the axes “b” and “c”. The anisotropy of thermal expansion increases as the molybdenum equivalent of the alloy increases.

Even a small doubling of individual lines on diffraction patterns of quenched titanium alloys indicates that the lattice is orthorhombic

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